
The Effect of a Machined Collar on Coronal Hard Tissue Around Titanium Implants: A Radiographic Study in the Canine Mandible

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Purpose: The purpose of this study was to radiographically evaluate the effect of a machined titanium coronal collar on the marginal bone around 1-part endosseous dental implants placed at different heights relative to the bone crest. **Materials and Methods:** Sixty dental implants were placed in edentulous spaces bilaterally in 5 foxhounds. Thirty test implants had a sandblasted, large-grit, dual acid-etched surface (SLA) over the entire length of the implant. The other 30 implants (control) had a machined collar around the most coronal 1.8 mm of the implant; an SLA surface covered the remainder of the implant. Both control and test implants were placed at 3 distinct levels relative to the bone crest. Six implants (3 control and 3 test) were randomly placed side by side in each hemimandible. Radiographs were taken at placement (baseline) and monthly for 6 months postplacement using a standardized radiographic template. **Results:** Fifty-eight of the implants integrated and were analyzed on each proximal surface. Bone loss occurred around all implants over the 6 months of the study. In general, implants placed with the top of the SLA surface above the bone crest had significantly less bone loss than implants with the top of the SLA surface placed flush with the bone level. Apically placed implants had greater bone loss than coronally placed implants. The magnitude of bone loss around paired control and test implants was approximately the same. **Discussion and Conclusion:** The least bone loss with each implant type was observed when the top of the implant was placed above the alveolar crest. When there was no machined collar, the least distance from the implant top to the bone crest (not, however, the least bone loss) was observed when the top of the implant was level with the bone crest. INT J ORAL MAXILLOFAC IMPLANTS 2005;20:677-686

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All dental implant-supported restorations have interfaces between the implant body and the definitive prosthetic crown. Some configurations (traditionally called submerged or 2-piece systems) also have another interface at the bone crest level. In other designs (traditionally called nonsubmerged or 1-piece systems), no interface is present at the alveolar crest. An interface at the bone crest level can have a significant influence on the bone level around the implant,¹⁻⁴ the soft tissue dimensions,⁵⁻⁷ and the amount of inflammatory cells.⁸ Thus, an interface and the inflammation associated with the interface may have a direct impact on the final level of marginal bone found around that implant. Consequently, the implant surgeon may need to consider the apico-coronal positioning of the implant as much as the buccal-lingual or mesial-distal positioning of the implant.

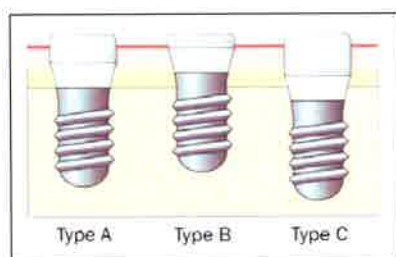


Fig 1 Schematic diagram of control implants at time of implant placement in relation to the crest of the bone. Soft tissue dimensions are adapted from the literature. The dark red area represents the vertical dimension of the sulcus depth, the pink area the junctional epithelium, and the yellow area the connective tissue contact.

Another aspect of implant design that has been shown to influence the level of the bone around the implant is the character of the surface of the implant. For example, many studies involving descriptive and functional analyses demonstrate greater bone-to-implant contact for rough-surfaced implants compared to more smooth implant surfaces.⁹⁻¹² Additionally, the bond between the implant and the surrounding bone is greater with rough-surfaced implants than with smooth implants, as shown by removal torque values.¹³ The use of rough-surfaced implants, the advantages of which were first demonstrated in animals, has had a significant effect on implant success in patients.¹⁴ Data from human clinical experiences support the advantages of implants with a roughened surface documented in animal and *in vitro* studies.

Cochran and associates¹⁵ utilized the advantages of a roughened implant surface (Straumann's sand-blasted, large-grit, acid-etched implants [SLA]; Straumann, Waldenburg, Switzerland) in a multicenter human prospective clinical trial. This trial demonstrated such implants can be loaded in patients with high success rates after a shorter-than-conventional healing period (6 weeks versus the usual 3 to 6 months). In this clinical trial, implant integration was evaluated by resistance to 35 Ncm of force without countertorque stabilization. This force was applied to abutments after 6 weeks for implants placed in relatively dense bone (types 1 to 3) or after 12 weeks for implants placed in less dense bone (type 4). Results were documented for 110 patients with 326 implants after a 1-year postloading recall visit and for 47 patients with 138 implants who had completed a 2-year recall. Three implants were lost prior to abutment connection. In 307 cases, prosthetic restoration was commenced after a shortened healing period. The success rate for these implants, as judged by abutment placement, was 99.3% (with an average healing

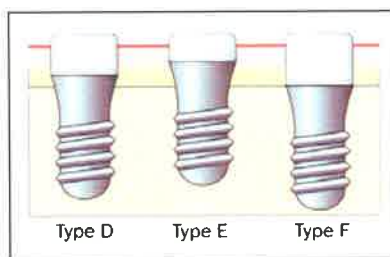


Fig 2 Schematic diagram of experimental implants at time of implant placement in relation to the crest of the bone. Soft tissue dimensions are adapted from the literature. The dark red area represents the vertical dimension of the sulcus depth, the pink area the junctional epithelium, and the yellow area the connective tissue contact. The rough-smooth border is at the shoulder of the implant; in other words, the top of the implant, the implant-abutment interface, is the rough-smooth border.

time of 49 days). The healing time was successfully reduced for 99.2% of the implants. Thus, based on this study and others,^{16,17} roughened titanium implant surfaces have modified patient treatment protocols.

The purpose of the present study was to evaluate the influence of a machined collar on the level of bone around an implant. Although bone loss was expected to be observable in all implants over time, the study was designed to determine whether bone loss was accelerated or affected in regard to magnitude by implant design and/or placement level to the degree that systematic differences could be observed 6 months postplacement in dogs.

MATERIALS AND METHODS

Study Design

Two sets of implants were systematically evaluated in dogs: the control implants, commercially available implants with a 1.8-mm machined collar, and the test implants, whose surface was roughened to the top of the implant (ie, no machined collar). Furthermore, the position of the top of the implant in relation to the alveolar crest was also evaluated. Therefore, control implants were placed with their rough-smooth border either at the bone crest level, 1 mm above the crest, or 1 mm below the crest (Fig 1), while test implants (which featured a rough surface that was flush with the implant shoulder) had the shoulder placed at the bone crest level, 1 mm above the alveolar crest, or 2 mm above the crest (Fig 2). To ascertain the bone response to implant placement, radiographs were obtained at the time of placement and at 1-month intervals until the dogs were sacrificed at 6 months. From the radiographs, the amount of bone loss was determined by the location of the first bone-to-implant contact (fBIC), ie, the most coronal point of bone-implant contact.



Animals

Five lab-bred male American foxhounds approximately 2 years old and weighing 30 to 35 kg were used for this study. All procedures were approved by the Institutional Animal Care and Use Committee of the University of Texas Health Science Center at San Antonio. All animals were free of heartworms and were quarantined. At the beginning of the study, the dentition was cleaned. Furthermore, an oral hygiene program was carried out throughout the whole study. The hygiene procedure consisted of a mechanical tooth brushing 2 times per week utilizing a soft toothbrush, Plak Out (Hawe Neos, Bioggio, Switzerland), and a 0.2% chlorhexidine digluconate gel.

Extractions

Tooth extractions were performed under general anesthesia and sterile conditions in an operating room. A 4% thiopental-sodium solution (0.4 mL/kg) was administered intravenously as a premedication. The dogs were placed on a heating pad, intubated, and inhaled with 1.5% to 2% isoflurane. They were monitored with an electrocardiogram during the surgery. After disinfection of the surgical site with 10% povidone-iodine solution and 1% titratable iodine, 2% lidocaine hydrochloride with epinephrine 1:100,000 was administered, and all premolars and first molars were carefully extracted. Prior to extraction, the remaining teeth were scaled and cleaned, and P₂ to M₁ were sectioned to avoid tooth fracture. Adaptation of the wound margins was achieved with interrupted sutures.

On the day of surgery, the dogs received 20 mg of the analgesic nalbuphine subcutaneously in 2 doses (10 mg/mL). Three milliliters of the antibiotic benzathine penicillin with penicillin G procaine (150,000 IU) were administered subcutaneously once every 48 hours for 7 to 10 days. For suture removal, after a period of 7 to 10 days, the animals were briefly anesthetized using a combination of xylazine (1.1 mL/15

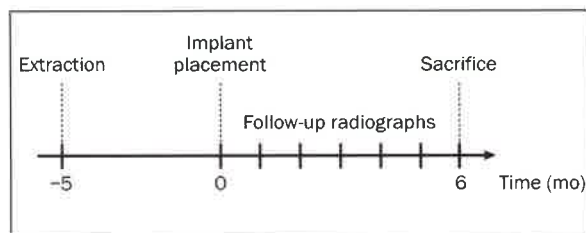


Fig 3 (Left) The most coronal 1.8 mm of the control implants (left) had a relatively smooth machined titanium surface; the remainder of the 9-mm implant had an SLA surface. The test implants (right) had no machined collar; thus, the SLA surface was 9 mm in vertical height.

Fig 4 (Above) Study design and timeline.

kg by weight; 7.1 mg/mL), acepromazine (2.1 mg/mL), atropine (0.1 mg/mL), and ketamine (50.0 mg/mL). Prior to suture removal, the local wound area was carefully cleaned with 0.12% chlorhexidine gluconate-soaked gauze.

Implant Designs and Surfaces

Two different designs of cylindrical titanium implants (control and test) with a full-body screw shape were made from cold-worked grade IV commercially pure titanium. For all implants, the inner diameter was 3.5 mm, the outer diameter was 4.1 mm, and the total length was 9 mm. The rough, apical portion of each implant consisted of a sand-blasted, large-grit, and HCl/H₂SO₄ dual acid-etched surface. The upper 1.8 mm of control implants (Esthetic Plus; Straumann) had a relatively smooth machined titanium surface. For test implants, the SLA surface was 9 mm in vertical height, with no machined collar (Fig 3).

Implant Placement

Implant placement was performed similarly to previously described procedures.² Briefly, implants were placed under the same surgical conditions as tooth extractions (sterility, operating room, and anesthesia) after a healing period of 5 months (Fig 4). A crestal incision was made to maximize keratinized tissue on each side of the incision. Mucoperiosteal flaps were carefully reflected on the lingual and buccal aspects. The mental foramina were exposed prior to implant placement. The edentulous osseous ridge was carefully flattened with an acrylic resin bur with copious irrigation with chilled sterile physiologic saline. Measurements were made using a Boley gauge to help randomly distribute 6 implants (3 control and 3 test) on each side of the mandible. Implant osteotomy was performed with torque reduction rotary instruments at 500 rpm using chilled saline. Implants were placed with an insertion device and hand ratchet; they were not submerged.

Six combinations of implants and placement positions were studied; these were labeled types A through F. For types A, B, and C, control implants were used (Fig 1). Type A implants were control implants with the rough-smooth border placed flush to the bone crest; for type B, the rough-smooth border was 1 mm above the bone crest; and for type C, it was 1 mm below the bone crest. For types D, E, and F, test implants were used (Fig 2). For type D, the top of the implant was placed 1 mm above the bone crest; for type E, it was placed 2 mm above the bone crest; and for type F, it was placed flush with the bone crest. Healing screws of various sizes were used so that, although the locations of the implant tops varied in relation to the alveolar crests, all terminated at the same level.

If necessary, periosteal relieving and contouring incisions were made on the buccal and lingual aspects to achieve tension-free wound closure, and a small V-shaped gingivectomy was performed for close adaptation of the mucosa to the transmucosal portion of the implants. Horizontal mattress and interrupted sutures were placed. The dogs received the same medications given after the tooth extractions. However, to reduce swelling, the dogs received 2 mL of the anti-inflammatory dexamethasone (2 mg/mL) intramuscularly on days 1 and 4. The sutures were removed after 7 to 10 days. A soft diet was utilized for the duration of the study.

Follow-up Period

Beginning 2 weeks after implant placement, oral hygiene procedures were carried out 2 times a week using 0.2% chlorhexidine gel in combination with a soft toothbrush. The healing abutments of all implants were disconnected and immediately tightened without removing the abutment at monthly intervals after implant placement surgery to imitate clinically relevant steps.

Radiographic Evaluation

Fabrication of the Radiographic Template. At the time of implant placement, an individual impression was made using customized trays fabricated from light-polymerizing acrylic resin, as has been described previously.¹⁸ A master cast was made using die stone. Grooves were made on the lingual side of each edentulous ridge (soft mouth floor area) to allow accurate positioning of the periapical radiograph (Ultraspeed film, size 3; Kodak, Rochester, NY) mounted on an x-ray bite block. Two ideally placed bite blocks were rigidly connected by a horseshoe-shaped acrylic resin bar and individual acrylic resin inverse U-shaped attachments, providing space for an attachment to the dog jaw. At both the mesial and distal

ends of the template, customized soft polyvinyl siloxane records from the cusps of the canine and second molar, respectively, were attached to the acrylic resin bar to allow for precise repositioning and stabilization of the radiographic template. Reversible adhesive tape was used to firmly attach the template to the dog's mandible. Finally, the ring of the beam-aiming devices was customized with autopolymerizing acrylic resin for an even better and more reproducible fit and better alignment of the long x-ray cone. Thus, an optimum parallel and perpendicular standardized radiographic technique was created to minimize errors of angulation and distortion.

Image Acquisition. At suture removal, 7 to 10 days after surgery, baseline standardized periapical radiographs were taken while the dog was under intravenous anesthesia. Exposure parameters were 70 kVp, 15 mA, and 0.25 seconds at a focus-film distance of 37 cm. For better film quality, manual development was carried out according to the manufacturer's recommendations. Radiographs were repeated monthly until completion of the study.

Image Capture and Digitizing. Radiographic image alignment and analysis were performed by a single examiner.² This has been shown to increase the consistency and reliability of the measurements.¹⁹ The radiographs were converted to 640 × 480-pixel digital images using a calibrated video camera and a 50-mm lens with an aperture of 8. The images were initially displayed on a 43-cm video monitor, where they were checked for their sharpness as well as submitted to a first coarse alignment. The range of optical densities in the radiographic image was converted into 256 different gray pixel values. A value of 0 represented a completely dark area, whereas a value of 255 described the lightest area on the film. Prior to image capture, transillumination was adjusted so that the crestal area of the image had pixel values of 120 to 200. This ensured optimum visualization of the bony margin of the most coronal area adjacent to the implant. The image was then digitized by a frame grabber board, supported by a personal computer. The calculated image pixel size in this investigation was 62.5 μm. Linear measurements were made from the bottom of the implant (BI) to the first bone-implant contact (BI-to-fBIC) both mesially and distally. A software program was used to analyze each calibrated image.

Power Analysis and Statistical Methods

A power analysis was conducted to determine the number of dogs that were necessary to detect population mean differences of 1 mm or more among the 6 implant study design types using a mixed-model analysis of variance (ANOVA), with $P < .05$ considered

statistically significant and a power of 80%. As there was sufficient space on each side of a dog's mandible to place 6 implants, it was possible to place 2 of each type within each dog. Using PASS software (NCSS, Kaysville, UT), it was determined that a sample of 5 dogs would give the study sufficient power. In each hemimandible, sites for implant placement were numbered 1 to 6, with 6 representing the most distal position of the mandibular arch. Ten sets of implant type arrangements were created such that no more than 2 implants of a specific type were placed in any site. The 10 sets of implant type arrangements were then randomly assigned to the 10 hemimandibles in the 5 dogs.

Measurements were obtained from the radiographs based on the fBIC observed for the mesial and distal sides of each implant and adjusted for distortion using the total length of the implant. The adjusted mesial and distal values were then compared to ensure that there was sufficient agreement to permit averaging of each pair so that each implant had a single representative BI-to-fBIC value for each time point.

These data were analyzed using a mixed-model repeated measures ANOVA to check whether implant design types differed in a consistent fashion across time for each dog. This analysis was done to ensure that the implants were placed in accordance with the study design, and that no serious problems with implant integration occurred during the course of the study. The mixed-model ANOVA tested the main effects of implant design (control versus test), position of the top of the SLA surface relative to the bone crest at placement (standard, coronal, or apical), and time, as well as the interactions among these 3 effects, with all results adjusted for any dog effect. Two additional effects relating to the placement of implants, position in the arch and mandibular side, were tested to check for possible confounding of results. If any of the F-tests were significant ($P < .05$), then relevant pairwise comparisons using Bonferroni-adjusted unpaired Student *t* tests, excluding any dog effect, were performed to identify differences of interest among implant-placement combinations A through F across time.

In addition to calculating bone loss at monthly intervals, the amount of bone loss observed from the time of placement to 6 months after placement was calculated using the averages of the mesial and distal bone loss values at baseline and 6 months. Bone loss was measured in millimeters and as a percentage of the baseline value. To ensure that the implant-placement combination types had similar placement levels of the rough/smooth border or top of the implant relative to the bone crest, type A (control, flush) was paired with type F (test, flush), and type B

(control, 1.0 mm above) was paired with type D (test, 1.0 mm above). Two mixed-model ANOVAs were performed to investigate possible implant type differences for the 2 measures of bone loss. The mixed-model ANOVAs tested the main effects of implant design (control versus test), and position of the top of the SLA surface relative to the bone crest at placement (eg, flush versus 1.0 mm above), the interaction between these 2 effects, and the possible confounding effects of position in the arch and side of the mandible, with all results adjusted for any dog effect. As before, Bonferroni-adjusted unpaired Student *t* tests were performed to identify differences of interest among implant types (A, B, D, and F) when the results of F-tests were significant ($P < .05$).

RESULTS

Clinical Findings

After implant placement, healing was uneventful in all dogs. One month after implant placement, 2 implants in 2 different dogs showed vertical radiolucent defects with marked mobility. These implants were removed. One implant was in the anterior aspect of the mandible; the other implant was in the posterior aspect of the mandible. All other implants ($n = 58$) demonstrated successful tissue integration; they exhibited ankylotic stability without clinical signs of peri-implant infection. No continuous peri-implant radiolucencies were apparent on the radiographs of these implants. Although oral hygiene was performed 2 times weekly, there was variation in the tissue response around the different implants. Peri-implant inflammation ranged from minimal to severe, hyperplastic inflammation. Tissue responses will be detailed in the histologic analysis of these implants.

Quantitative Radiographic Findings

Radiographs were taken at the time of implant placement and at 1-month intervals for 6 months. Data collected from radiographs included the total length from the bottom of the implant to the top of the healing abutment and the distance from the BI-to-fBIC on both the mesial and distal sides of the implant (Fig 5). Complete data across 6 months were available for 58 of the 60 implants. The 2 implants that failed, which were type F (test type) implants, were excluded from the analysis. To correct any distortion that may have occurred owing to the difficulty of obtaining radiographs in which the implant was not tilted relative to the film, the ratio of the actual implant measurement to the observed lengths of the radiographs was calculated for each implant at each time. In general, the ratios indicated that the

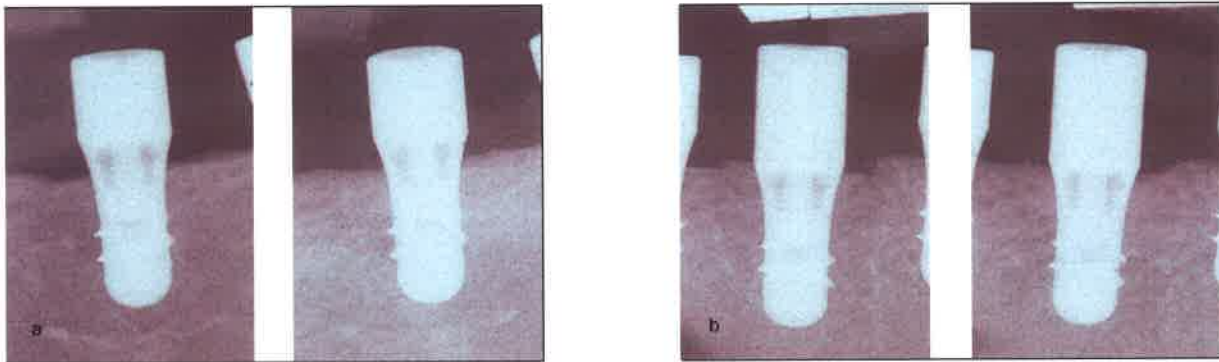


Fig 5 Radiographic changes from the BI to the fBIC from baseline to 6 months for (a) type A implants and (b) type F implants.

implant distances needed to be increased by an average of 5% to correct for radiographic distortion.

Two radiographs (1 anterior and 1 posterior) were always taken on each side of the mandible to ensure image capture of all the implants. The final data were initially captured on anterior radiographs. To ensure that the anterior view did not bias the measures, corresponding posterior radiographs showing images of the same implants were remeasured and compared to the images measured from the anterior radiographs. This allowed measurement error to be determined. Implant length and BI-to-fBIC (mesial and distal) did not differ by more than 0.5 mm for any of the 28 anterior-posterior pairs of radiographs.

Since there were 58 implants with complete radiographic data at 7 time points, there were 406 pairs of mesial and distal BI-to-fBIC values. After adjustment, the mesial and distal implant measures differed by less than 0.5 mm for 334 (82.3%) of the pairs, while 390 (96.1%) differed by less than 0.75 mm. The largest difference was 0.94 mm. An examination of the distribution of adjusted bone loss values for the 58 implants revealed that 1 type E implant had a 6-month bone loss of 1.79 mm or 21.8%; this implant was revealed to be an outlier upon examination of the box plot. This value was 0.59 mm, 6.8% greater than the second-highest bone loss value. As it was likely that this implant had systematic problems, including advanced bone loss, which were not present in the other 57 implants, it was excluded from the analysis.

For the repeated-measures model, all interactions among implant design, position of the top of the SLA surface, and time were nonsignificant ($P > .20$), while all main effects for these factors were significant ($P < .001$). For the possible confounders, position on the arch was nonsignificant ($P > .70$), but mandibular side was significant ($P < .01$), with measures for

implants placed on the right side longer than those for the left side by an average of 0.25 mm. As a result, the mixed-model repeated measures ANOVA was rerun to check for possible interactions between mandibular sides and implant design. All interactions among mandibular side, implant type, and rough-smooth border or top of the SLA surface position were nonsignificant ($P > .10$), so mandibular side was not a confounding effect (Table 1).

When implant types with relatively adjusted placement positions were compared (ie, A versus D, B versus E, and C versus F), test implants consistently had longer mean BI-to-fBIC distances than control implants at each time point; ie, test implants were placed deeper than control implants, as dictated by the study design ($P < .015$, Table 1). When the 3 types of control implants were compared (Fig 6a), it was observed that at all time points postbaseline (except 1 mo), type B implants, which were placed suprcrestally, had less bone loss than the other control implants, which were placed flush with or below the bone crest ($P < .001$). No significant differences ($P > .10$) were observed between types A and C. When the test implants (types D, E, and F) were compared (Fig 6b), it was observed that both type E implants and type D implants consistently had less bone loss than type F implants (Table 2; $P < .001$ and $P < .03$, respectively). At baseline, 4 months, and 6 months, type E implants had significantly less bone loss than type D implants ($P < .035$). For each implant type, mean bone loss decreased across time. The mean bone loss between baseline and 6 months was significant for all implant types ($P < .01$).

For the mixed-model ANOVA comparing 6-month bone loss in mm, the interaction between implant design and position of the top of the SLA surface, neither position ($P > .80$) nor the main effect of implant design ($P > .60$) was significant. However, the

Table 1 Adjusted Mean BI to fBIC in mm

Type/ time point	Mean	SD	Minimum	Maximum
A (n = 10)				
Baseline	7.800	0.537	7.10	8.68
1 mo	7.633	0.568	6.90	8.48
2 mo	7.486	0.576	6.61	8.47
3 mo	7.379	0.586	6.71	8.38
4 mo	7.256	0.405	6.83	7.86
5 mo	7.231	0.456	6.83	7.94
6 mo	7.176	0.515	6.60	7.97
B (n = 10)				
Baseline	6.973	0.508	6.23	7.63
1 mo	6.717	0.576	5.53	7.47
2 mo	6.691	0.485	5.82	7.39
3 mo	6.588	0.557	5.74	7.59
4 mo	6.562	0.456	5.74	7.26
5 mo	6.624	0.423	5.90	7.33
6 mo	6.605	0.348	5.87	7.21
C (n = 10)				
Baseline	8.108	0.406	7.69	8.97
1 mo	7.770	0.473	6.94	8.59
2 mo	7.617	0.400	7.20	8.40
3 mo	7.635	0.380	7.10	8.35
4 mo	7.550	0.357	6.95	8.13
5 mo	7.471	0.278	7.10	7.96
6 mo	7.422	0.404	6.83	8.08
D (n = 10)				
Baseline	8.376	0.390	7.73	9.17
1 mo	8.056	0.343	7.64	8.86
2 mo	7.988	0.205	7.70	8.39
3 mo	8.022	0.309	7.73	8.74
4 mo	7.864	0.314	7.36	8.32
5 mo	7.885	0.230	7.38	8.15
6 mo	7.947	0.220	7.56	8.23
E (n = 9)				
Baseline	7.831	0.505	7.04	8.68
1 mo	7.740	0.543	6.94	8.35
2 mo	7.706	0.453	6.81	8.22
3 mo	7.650	0.442	6.97	8.17
4 mo	7.516	0.392	6.87	8.06
5 mo	7.587	0.356	7.10	8.10
6 mo	7.428	0.481	6.60	8.11
F (n = 8)				
Baseline	9.063	0.577	8.53	10.14
1 mo	8.717	0.745	7.44	9.77
2 mo	8.607	0.581	7.60	9.37
3 mo	8.542	0.646	7.50	9.62
4 mo	8.370	0.498	7.57	9.02
5 mo	8.362	0.517	7.64	9.07
6 mo	8.328	0.522	7.53	8.97

main effect of placement position ($P < .015$) was significant, meaning that the amount of bone loss was influenced by implant position level (Table 3). In general, implants with the top of the SLA surface placed 1.0 mm above the bone crest (types B and D) had significantly less bone loss ($P < .015$) than implants with the top of the SLA surface placed flush with the bone crest (types A and F). Similar results were observed for percentage of bone loss; implant type-

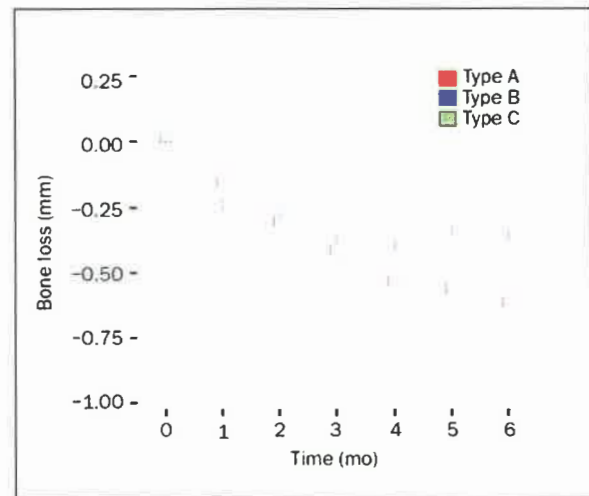


Fig 6a Mean bone loss for the control implants. Means were calculated by averaging mesial and distal bone loss for each implant. Bars show 95% confidence intervals.

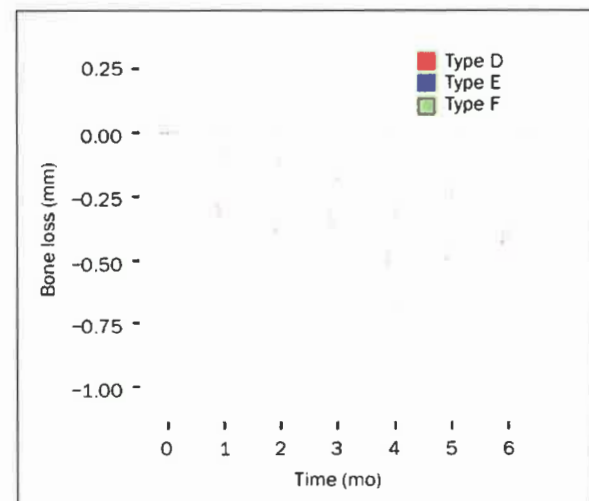


Fig 6b Mean bone loss for the test implants. Means were calculated by averaging mesial and distal bone loss for each implant. Bars show 95% confidence intervals.

position interaction ($P > .90$) and the main effect of implant type ($P > .70$) were insignificant, while the main effect of placement position ($P < .035$) was significant (Figs 7 and 8). In general, implants with the top of the SLA surface placed 1.0 mm above the bone crest (types B and D) had significantly smaller percentages of bone loss ($P < .03$) than implants positioned flush with the bone crest (types A and F, respectively) (data not shown).

Type	n	Mean	SD	95% CI	Minimum	Maximum
A	10	0.625	0.246	0.449–0.801	0.198	0.960
B	10	0.368	0.360	0.111–0.626	-0.260	1.020
C	10	0.686	0.398	0.401–0.971	-0.096	0.794
D	10	0.429	0.388	0.151–0.706	-0.034	0.661
E	9	0.402	0.224	0.230–0.574	-0.032	1.200
F	8	0.735	0.352	0.440–1.029	0.175	1.178

Type	Bone loss	Microgap–fBIC distance
A	0.63	2.43
B	0.37	3.17
C	0.69	1.49
D	0.43	1.43
E	0.40	2.40
F	0.74	0.74

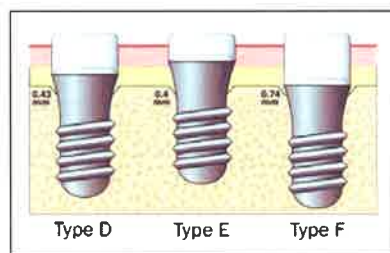
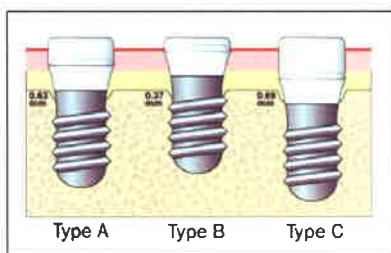


Fig 7 (Left) Schematic diagram of control implants at 6 months after implant placement. Mean bone loss from baseline to 6 months for each type is shown in millimeters.

Fig 8 (Right) Schematic diagram of test implants at 6 months after implant placement. Mean bone loss from baseline to 6 months for each type is shown in millimeters.

DISCUSSION

This study evaluated the radiographic changes over time of bone levels associated with 2 titanium implant designs placed side by side in the canine mandible. The major findings were

1. The magnitude of bone loss from the top of the SLA surface to the alveolar crest around paired control and test implants was approximately the same.
2. When test implants were compared to control implants, less bone loss was observed from the microgap (Table 3).
3. When the microgap was at the rough-smooth border (as in the test implants), the least amount of bone loss occurred when the microgap was 1 mm or more above the bone crest.
4. When the microgap was at the rough-smooth border, the distance between the microgap and the bone crest was the smallest when the top of the implant was level with the bone crest (Table 3).

A total of 57 implants comparing 2 different designs and 3 different locations in relation to the bone crest were evaluated. The difference between the 2 implant designs was the presence of a machined collar at the top of the control implants. The placement differences resulted from the rough-smooth border of the implant (for control implants) or the top of the implant (for test implants) being placed flush with, 1 mm below, or 1 or 2 mm above the crest. Fifty-eight of 60 implants were well integrated in

bone for the duration of the study, as evaluated by clinical and radiographic criteria. No increased mobility was detected on follow-up examinations, and no periapical radiolucencies were detected on any of the radiographs taken during the study.

As a result of the template used for taking the standardized radiographs, all implants could be well visualized over time and therefore included in the crestal height analysis. The data demonstrated that the magnitude of bone loss from the rough-smooth border to the alveolar crest around paired control and test implants was approximately the same. This means that the most coronally placed implants of each design (types B and E) had similar amounts of bone loss. Furthermore, these implants had the least bone loss compared to the other types of implants. This is consistent with previous experiments in which the most coronally placed implants also had the least amount of bone loss.² The reasons behind these results are unknown, but they may be related to the fact that the microgap, where bacterial contamination has been shown to occur, is located above the bone crest. Brogini and colleagues⁸ demonstrated that a substantial amount of inflammatory cells was associated with this interface; these cells could be responsible for the recruitment of cells capable of resorbing bone. Thus, having these cells some distance above the bone would minimize the likelihood of crestal bone resorption. This effect of distance from the bone being critical to the amount of bone loss could be analogous to what may be occurring around periodontally involved teeth. This phenome-

non has been referred to as an "extended arm" of gingival inflammation by Waerhaug,²⁰ an "effective radius of action" by Garant,²¹ and, more recently, an "inflammatory front" by Graves and Cochran.²²

An additional finding was that the greatest amount of bone loss occurred around the most apically positioned implants of each implant design (types C and F). In these cases, the microgap (interface) was placed closest to the bone, suggesting that the associated inflammatory cells were also closest to the bone crest. This relationship could have resulted in the recruitment of more bone-resorbing cells and thus, more crestal bone loss. This scenario is consistent with the idea of an inflammatory front. Additionally, the bone loss observed may also be attributed to the fact that a biologic width is associated with implants⁶ and therefore the bone loss that occurred allowed for connective tissue and epithelial attachment to the implant surface below the microgap.^{7,23} The mechanism for these biologic width changes may also be attributed to a contaminated microgap or interface^{24,25} and the associated inflammatory cells.⁸ In this case, the tissue changes that occurred may be attributed to the host's attempt to isolate or "wall off" the infection, which would be similar to what occurs in a periapical infection.²⁶

Another finding from this study was that the closer the microgap (interface) was to the rough/smooth border, the less bone loss was observed radiographically from the microgap. Previous studies have shown that bone loss around implants can be associated with both the microgap (interface) and with a rough-smooth border when no microgap is present.⁵ If an implant has both a microgap and a rough-smooth border at some distance from each other, cumulative bone loss may be attributed to the added effects of each (the microgap and the rough-smooth border). When the microgap and the rough-smooth border are at the same location, as with the test implants in the present study, then the cumulative bone loss (as was observed in this study) might be a reflection of only 1 of these phenomena (either the microgap or the rough-smooth border). This means that the observed bone loss from 1 effect may obscure or dominate and thus cancel or overcome the effect of the other. This suggests that when the microgap is at the rough-smooth border, the effects of these 2 phenomena are not cumulative and likely result from a similar mechanism of action. The results from the present experiment suggest this is the case (Table 3). For example, the distance from the microgap to the fBIC for all the test implants was less than for the corresponding control implants (1.43 mm for type D implants versus 2.43

mm for type A implants; 2.40 mm for type E implants versus 3.17 mm for type B implants; 0.74 for type F implants versus 1.49 for type C implants) (Table 3).

A further finding in this study, which reinforces previously published results, was that when the microgap and the rough-smooth border were at the same location, the least amount of bone loss occurred when the microgap/rough-smooth border was 1 mm or more above the bone crest. This was demonstrated in an early study comparing implants placed at different levels in relation to the alveolar crest¹ and reinforced in later studies where minimal crestal bone loss occurred when all implants were placed with their tops 1 mm above the bone crest.² This again suggests that an interface, with bacteria and associated inflammatory cells, should be positioned some distance away from the alveolar bone. Interestingly, in the present study, placing the microgap (top of the implant) 2 mm above the bone crest (test implant type E) did not produce significantly different results than placing the microgap only 1 mm above the crest (test implant D; mean bone losses of 0.40 mm and 0.43 mm, respectively). It is possible that the tissue changes observed around these types of implants are driven by a need to establish a biologic width dimension and that once this width has been established, no further tissue changes are necessary.

A final observation was that when the microgap and the rough-smooth border were at the same location (again, as in the test implants), the least distance from the microgap to the bone crest occurred when the top of the implant was positioned level with the bone crest (ie, in type F implants; Table 3). In this experimental situation, a mean of 0.74 mm of bone loss occurred. However, it should be noted that, of the test implants, this represented the greatest amount of bone loss (mean bone loss was 0.43 mm for type D and 0.40 mm for type E). It should also be noted that when the top of a flared implant is placed at the bone level (as with the type F implants in this study), the most cortical bone is removed (in a horizontal direction), which potentially compromises the blood supply to the remaining cortical bone. Thus, when deciding on implant design and placement, one should evaluate whether the amount of bone loss (both horizontally and vertically) or the distance from the microgap to the bone level is more relevant. It also needs to be emphasized that these results have been drawn from an evaluation of radiographs and not from histologic analysis. The defined hard and soft tissue locations are best evaluated by histologic processing of the tissue adjacent to the implant, and these results will be described in a future article.

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